

# **Structural Uncertainty of Radio Occultation Retrieval from Data Smoothing and Other Recent Developments**

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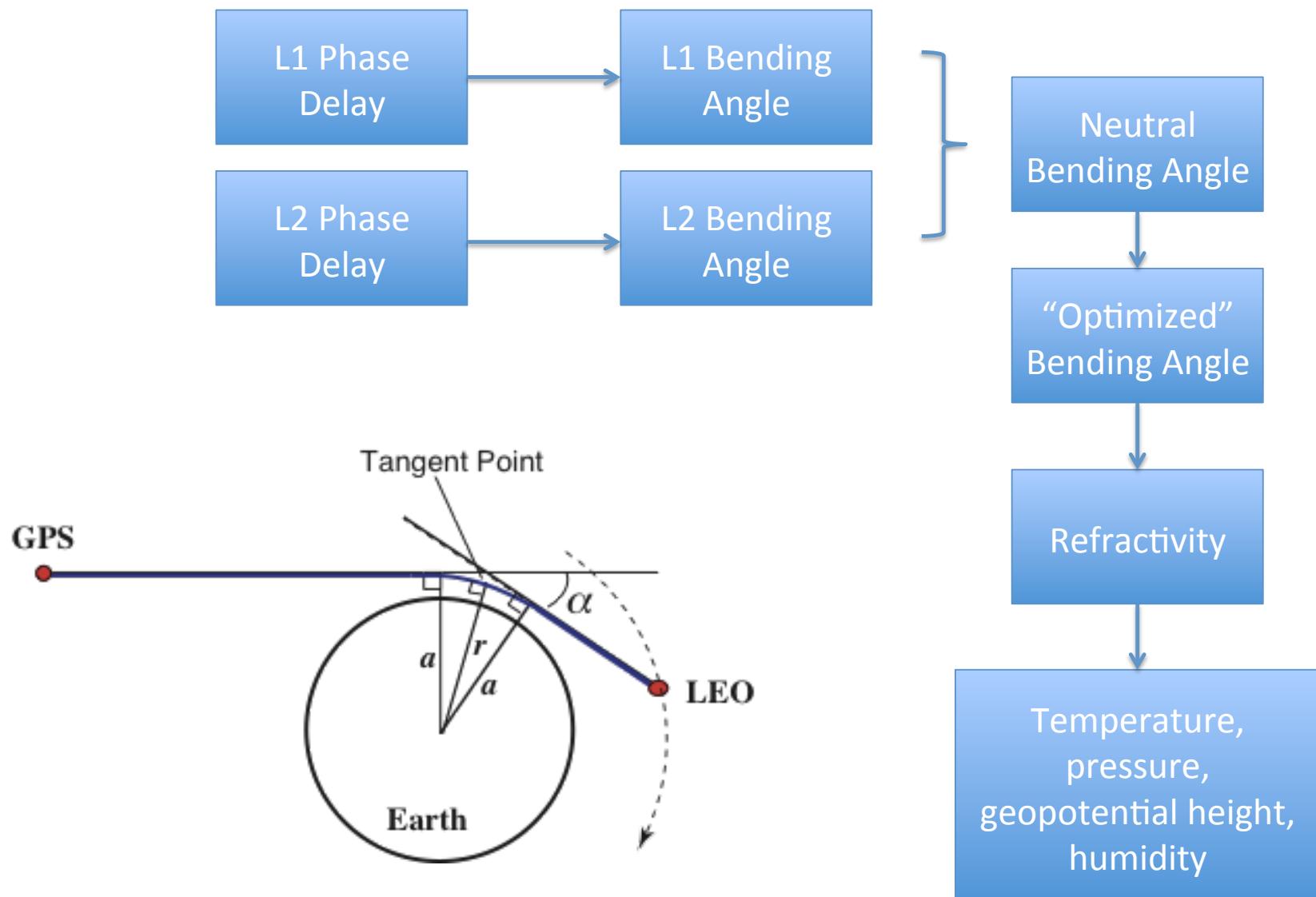
*Jet Propulsion Laboratory  
California Institute of Technology, Pasadena, CA, USA*

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April 29, 2015

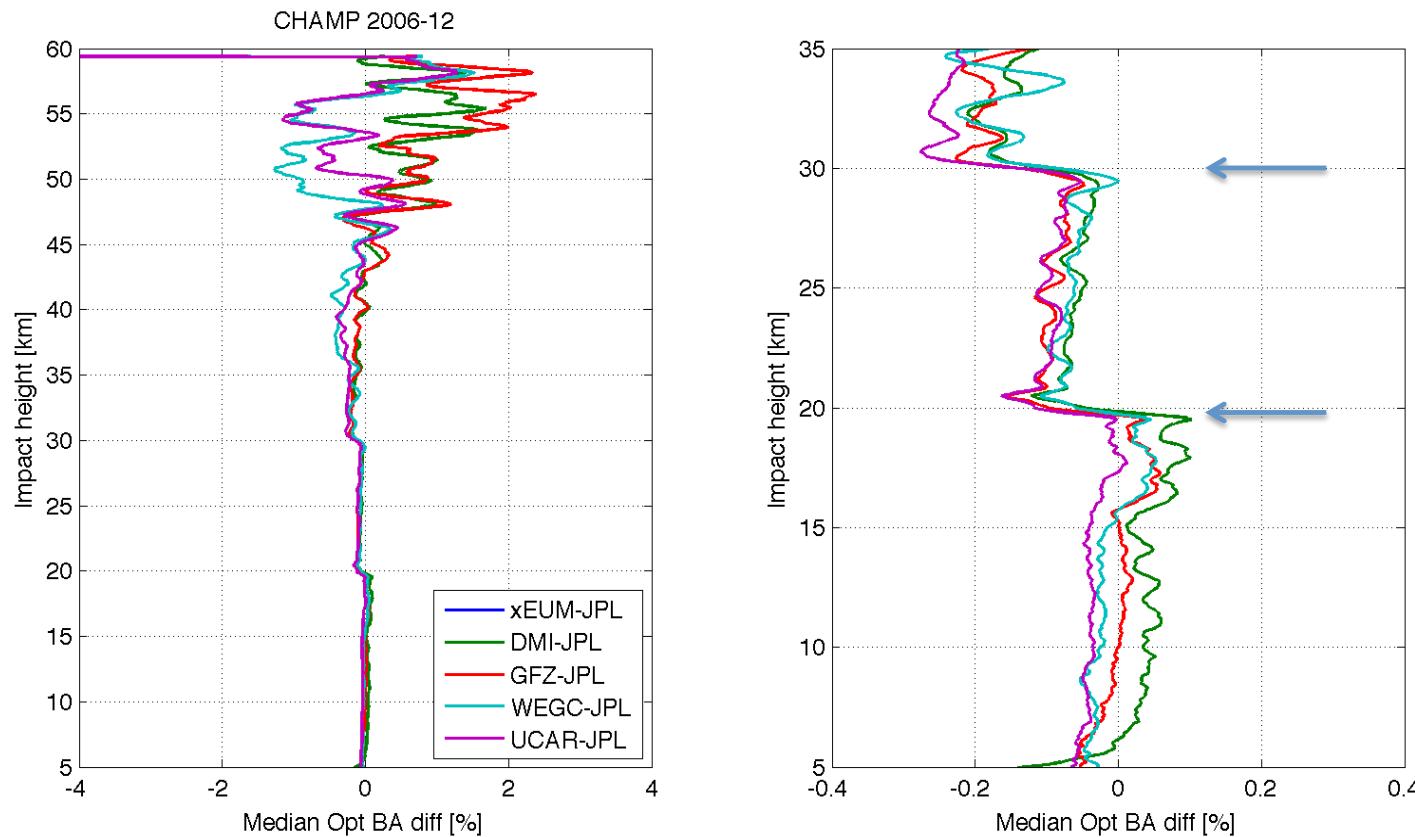
# Outline

- Progress in inter-center comparison study
  - Bias from phase smoothing
  - Remaining issues
- Recent developments
  - Residual ionospheric error
  - Refractivity coefficients

# Brief Review of RO Retrieval



# Inter-Center Comparison (Bending Angle)

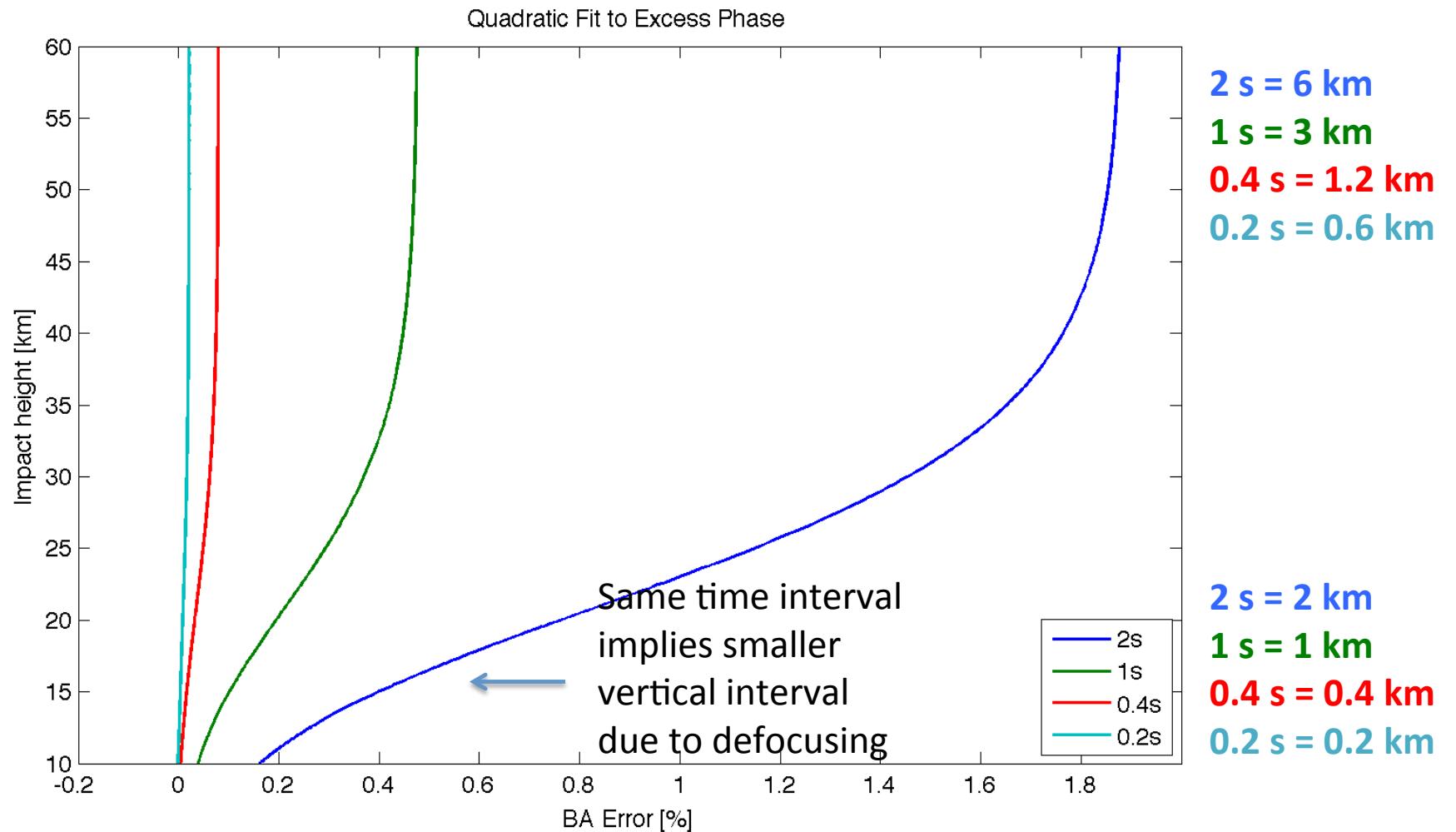


The abrupt jumps at 20 and 30 km occur where JPL changes its vertical smoothing intervals, suggesting that JPL phase smoothing algorithms might have introduced systematic biases.

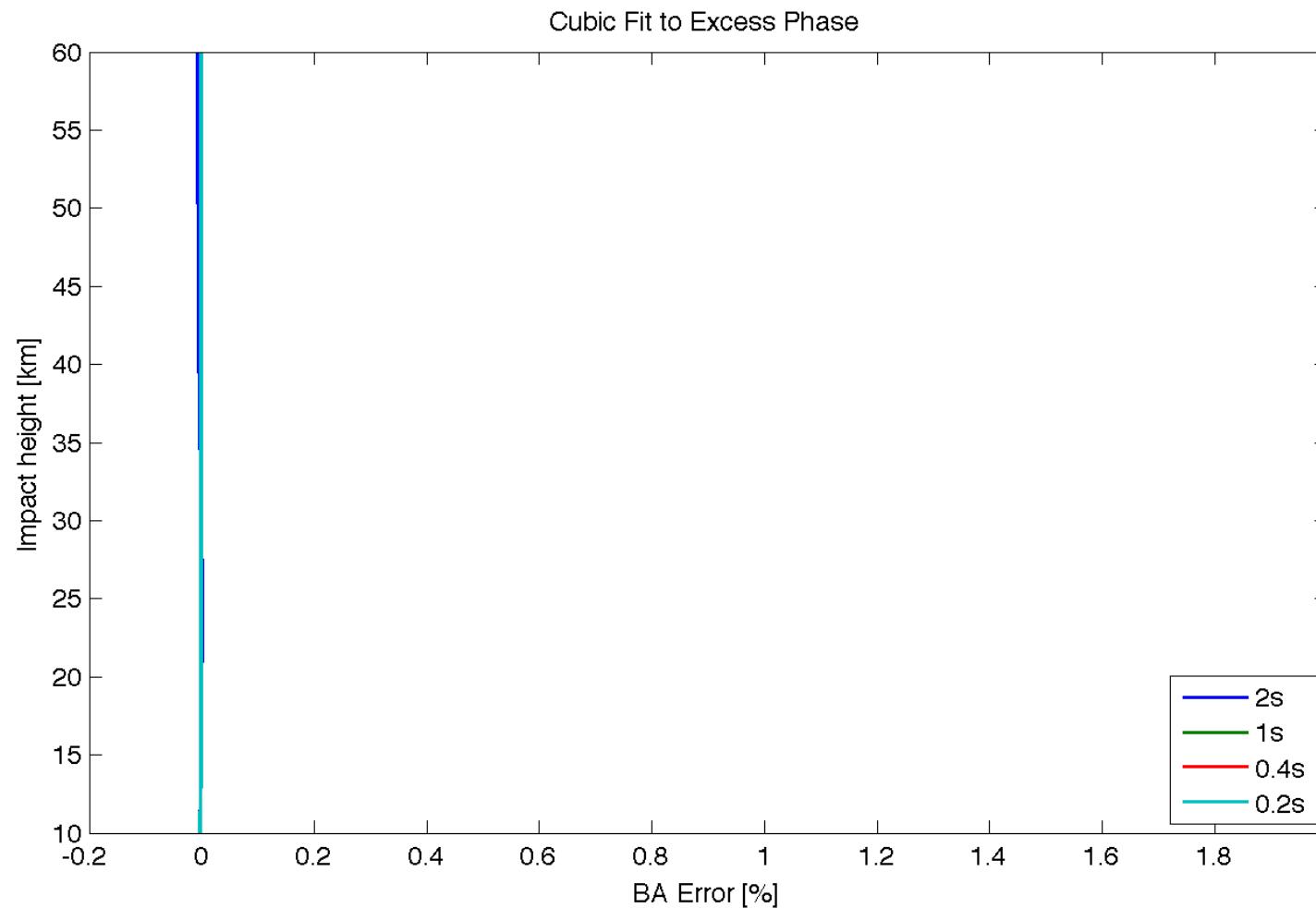
# Re-examining Phase Smoothing

- The raw phase measurements are available at high sampling rate (50 Hz or above).
- To reduce noise, the phase is typically smoothed using a low-degree polynomial over  $\sim 1\text{sec}$  time interval (equiv. Savitzky-Golay filter).
- A quadratic fit has been adopted in standard JPL processing.

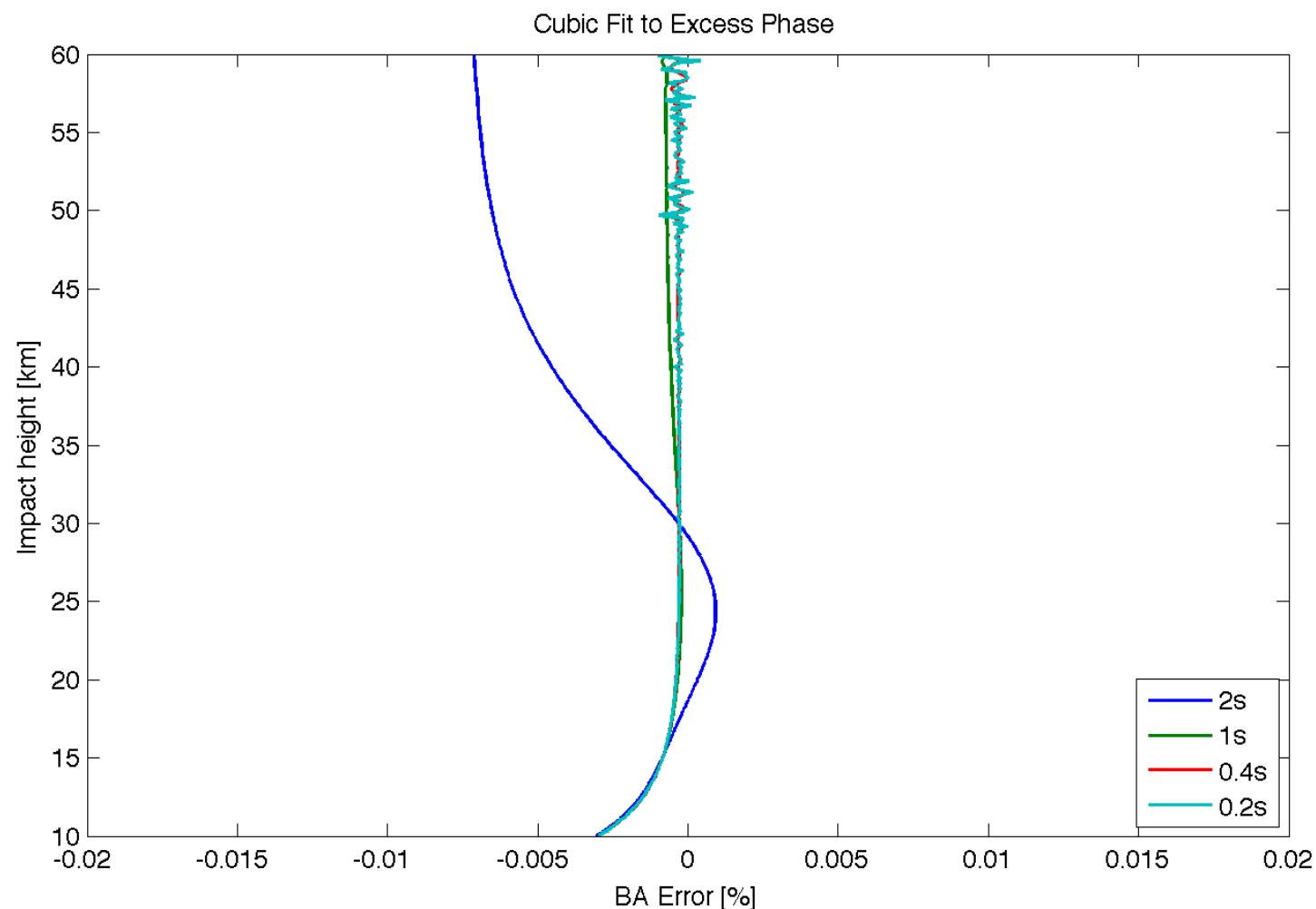
# Quadratic Phase Smoothing



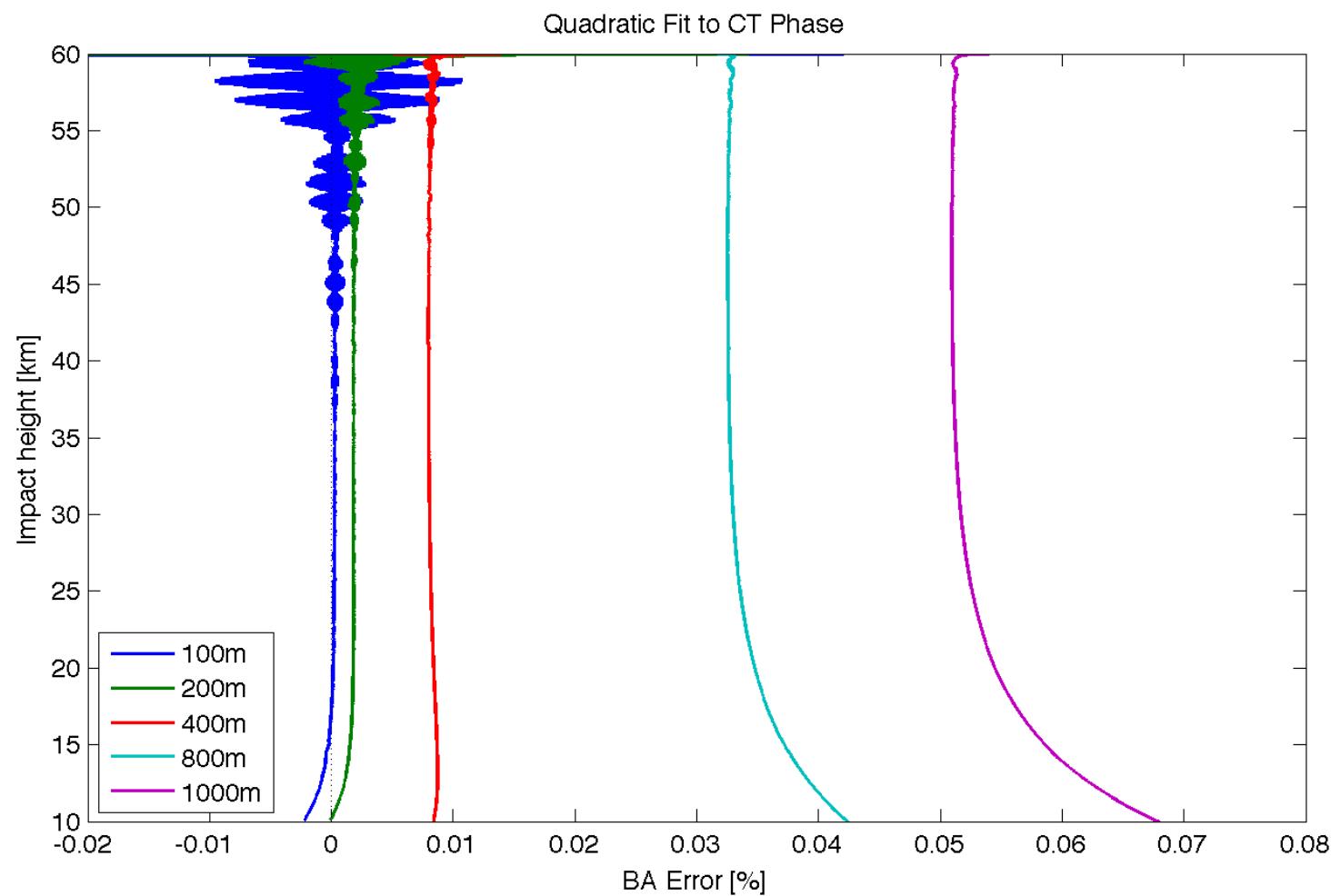
# Cubic Phase Smoothing



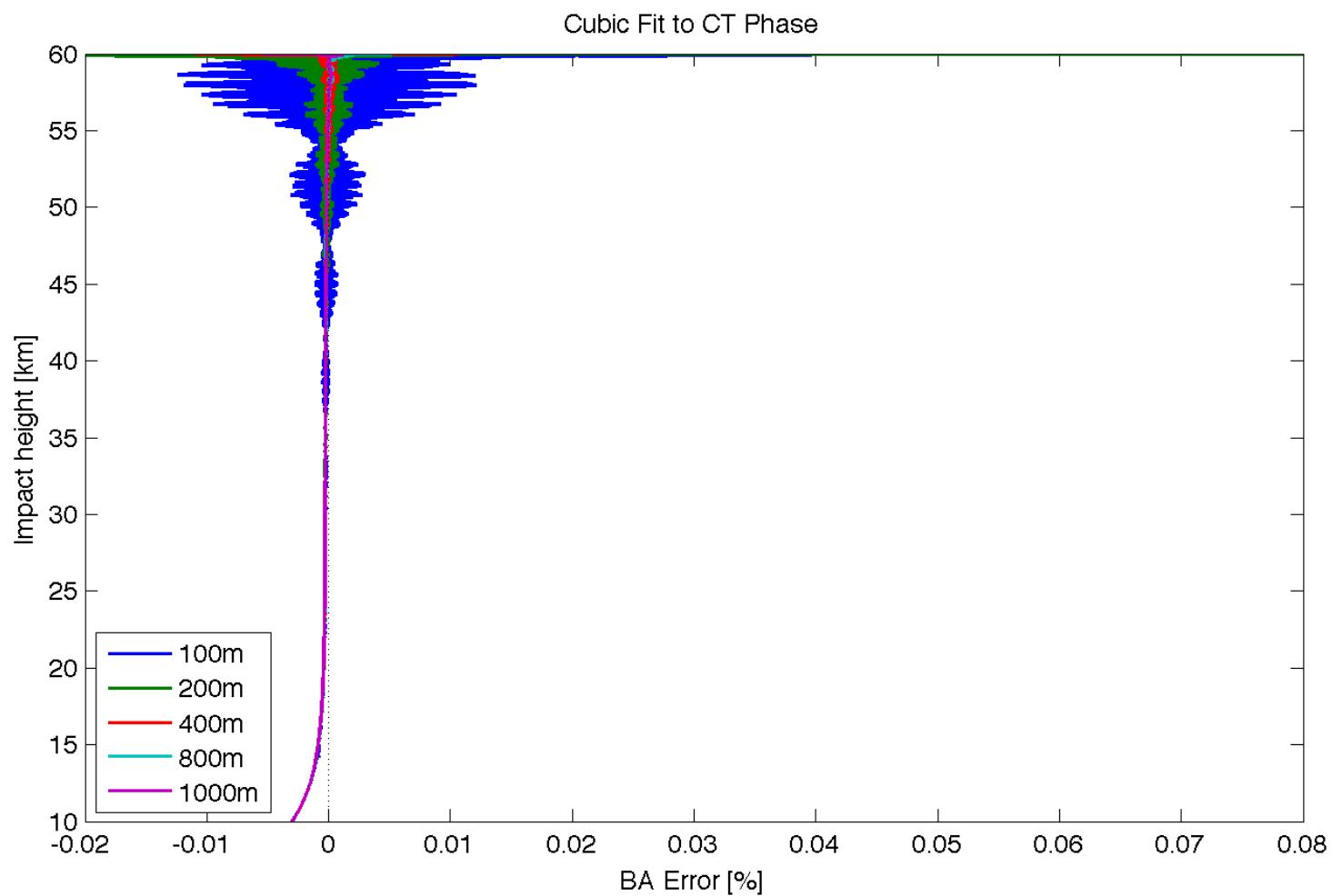
# Cubic Phase Smoothing

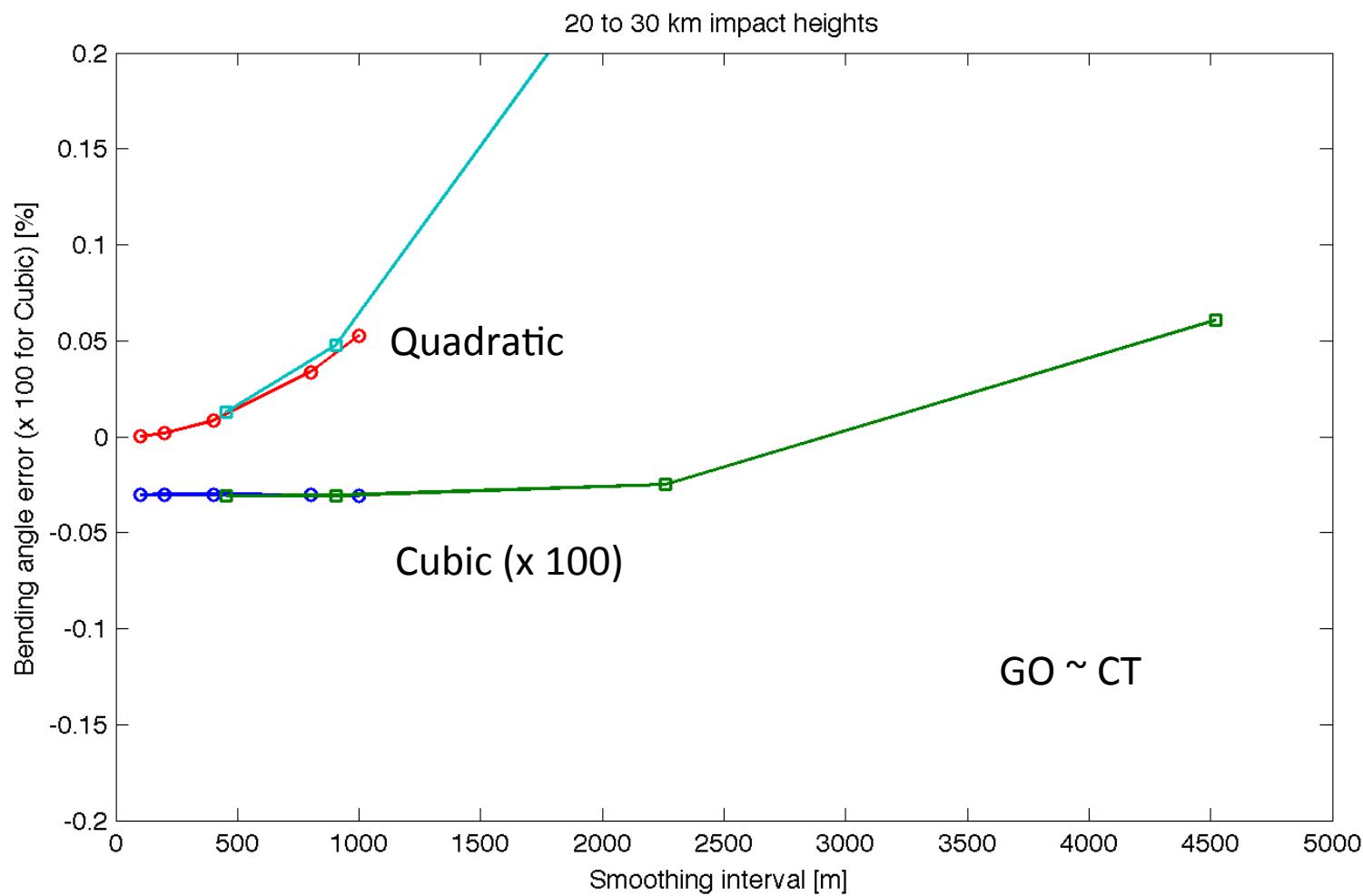


# Quadratic Smoothing: CT Phase



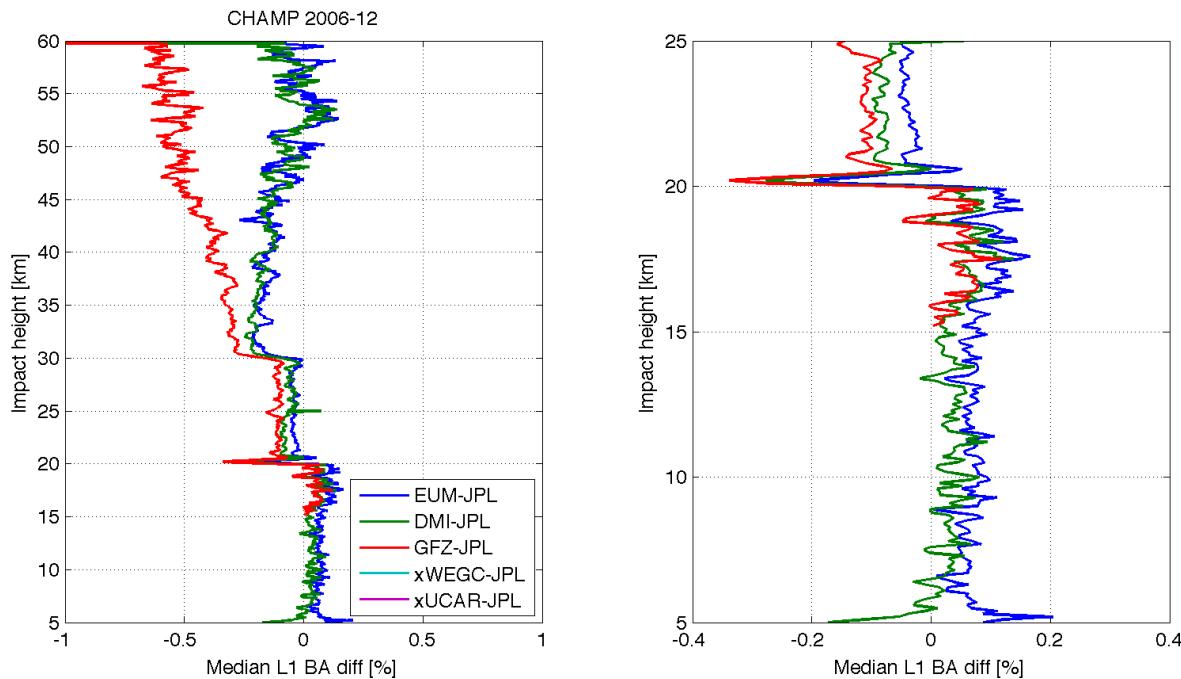
# Cubic Smoothing: CT Phase



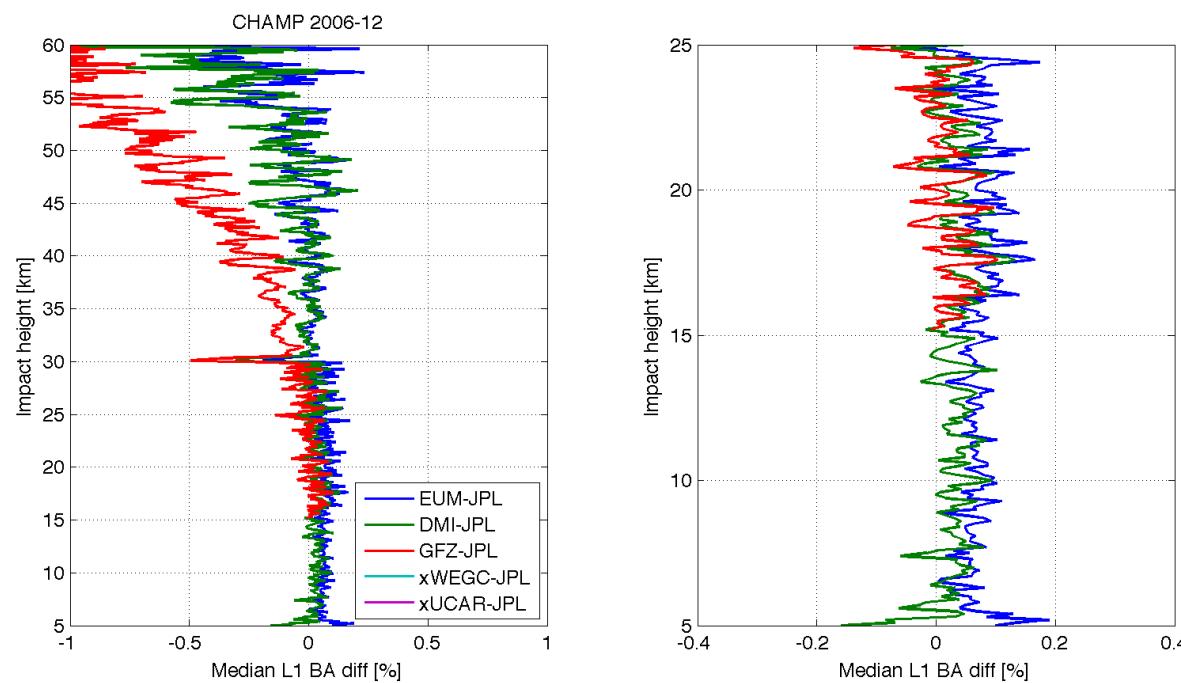


# L1 BA

Before

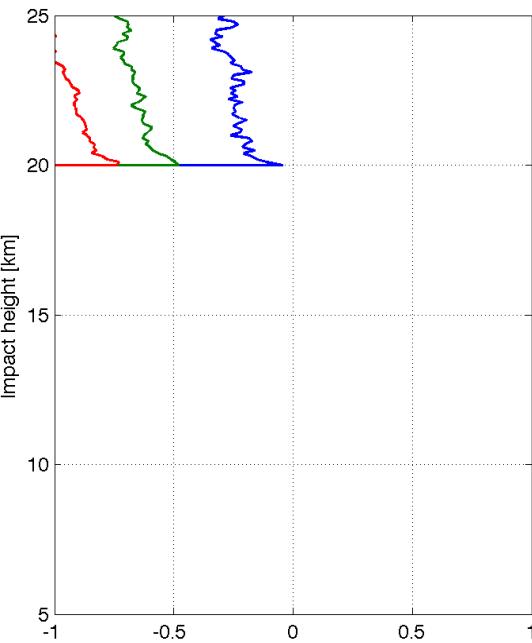
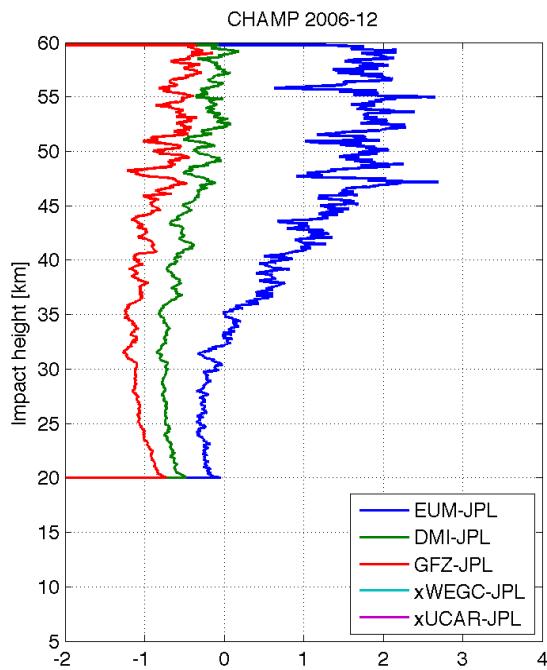


After

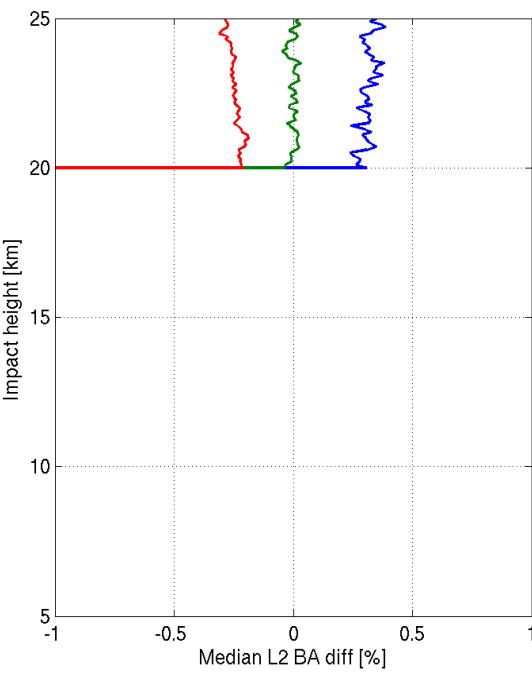
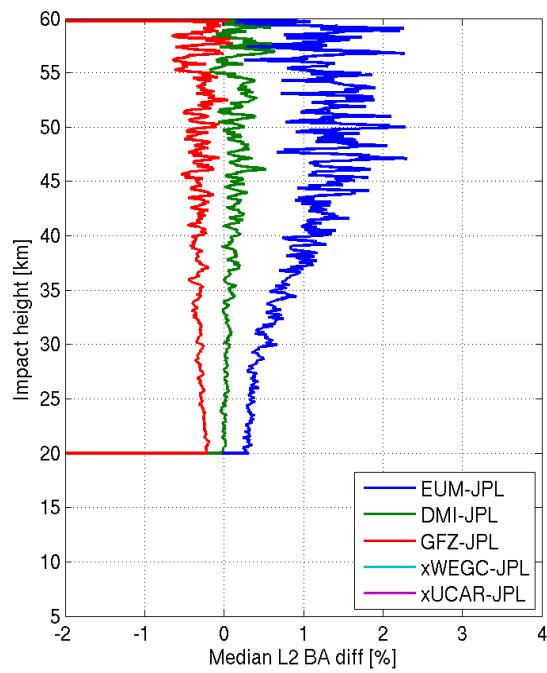


# L2 BA

Before

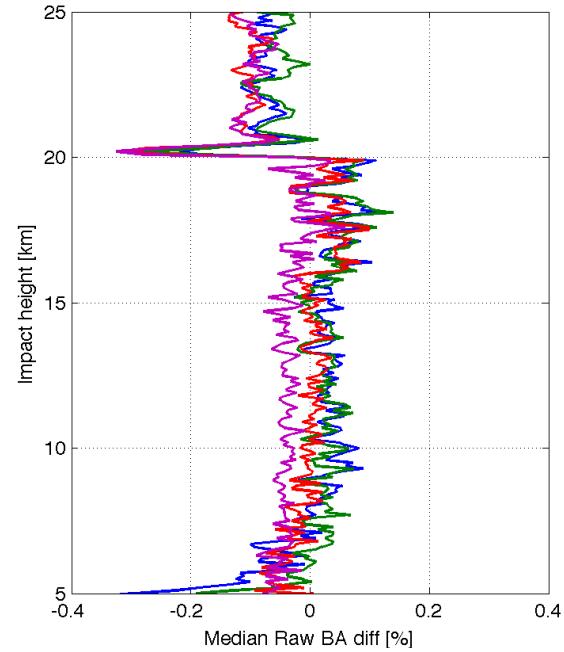
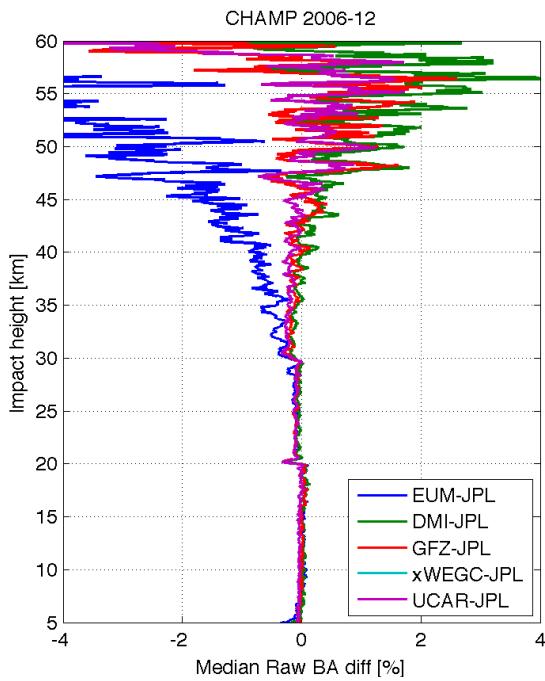


After

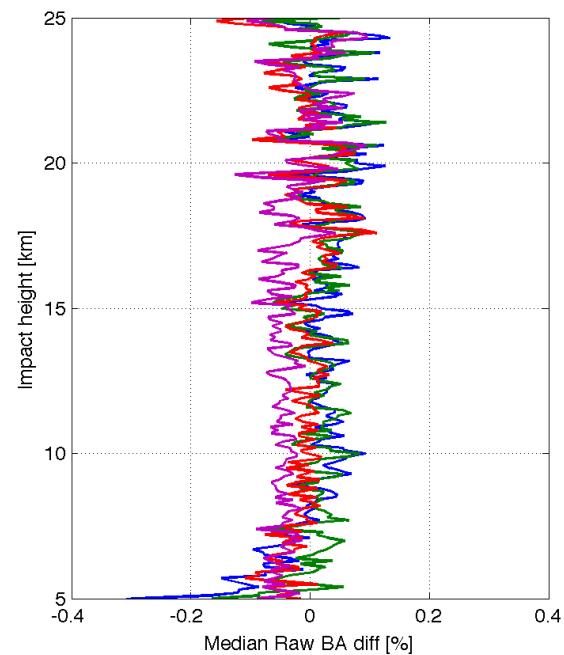
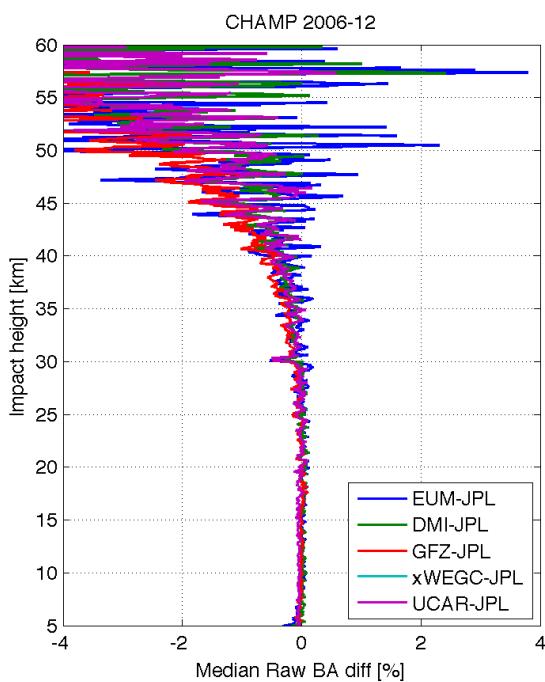


# Neutral BA

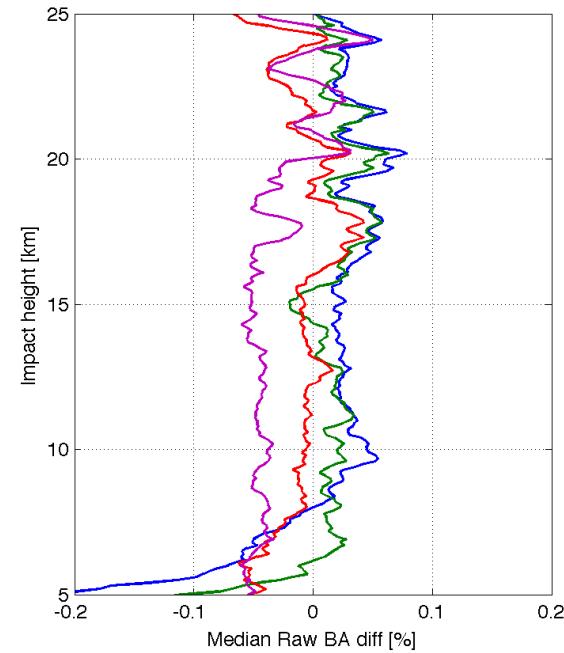
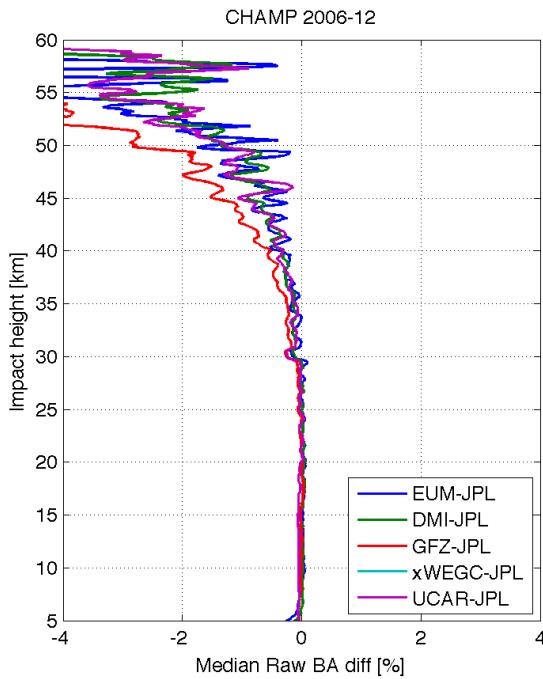
Before



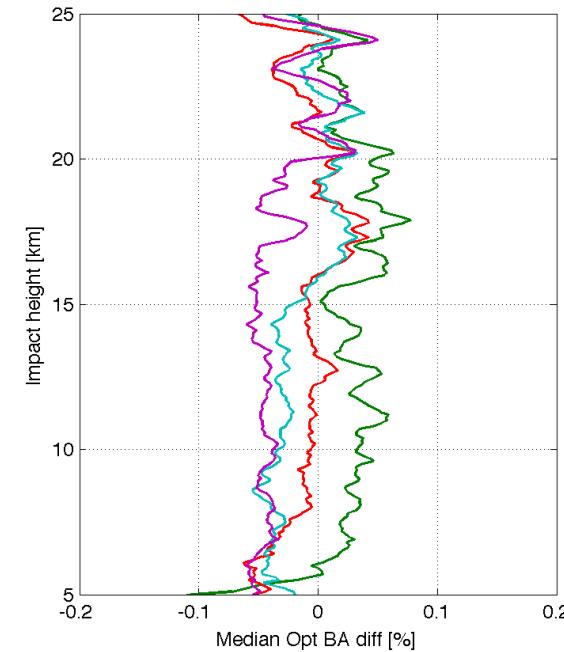
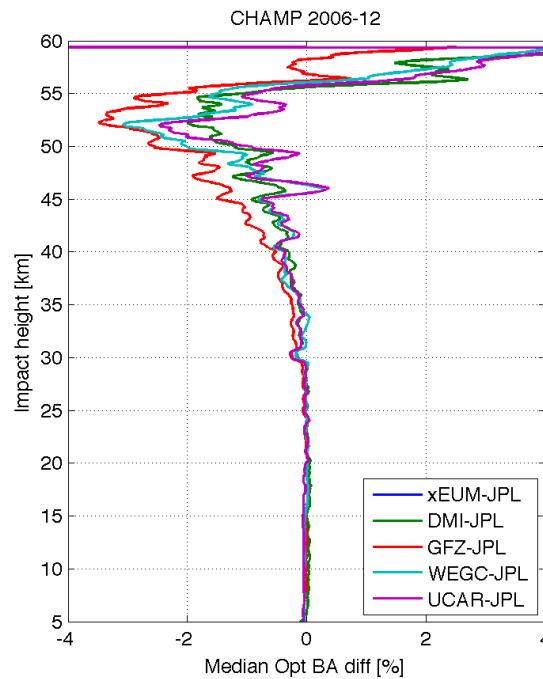
After



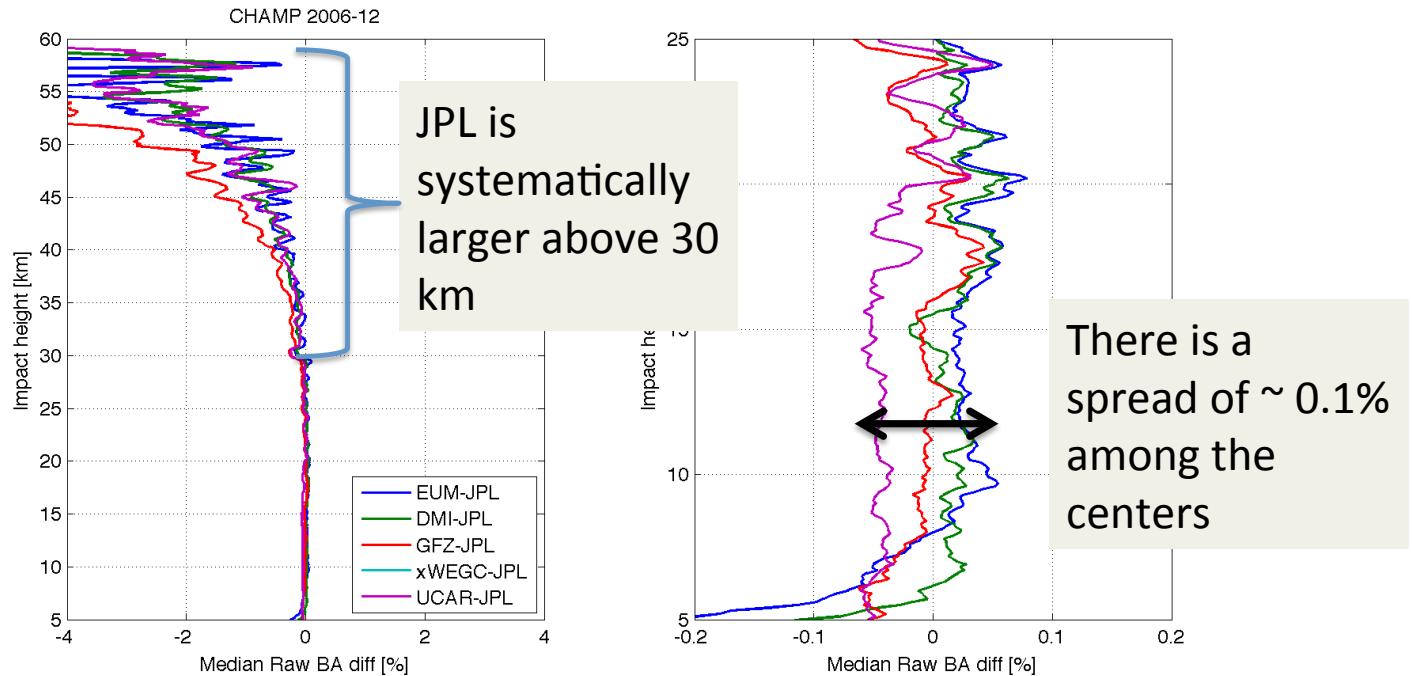
## Neutral BA



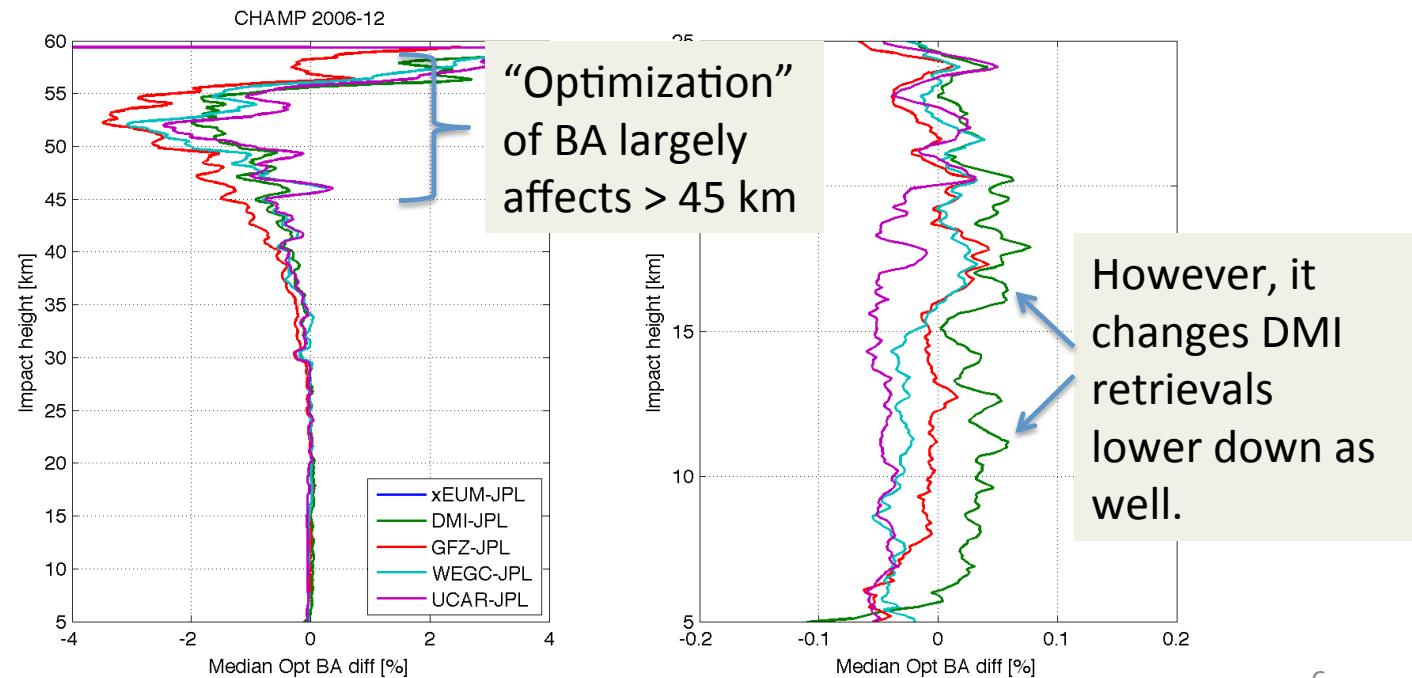
## Optimized Neutral BA



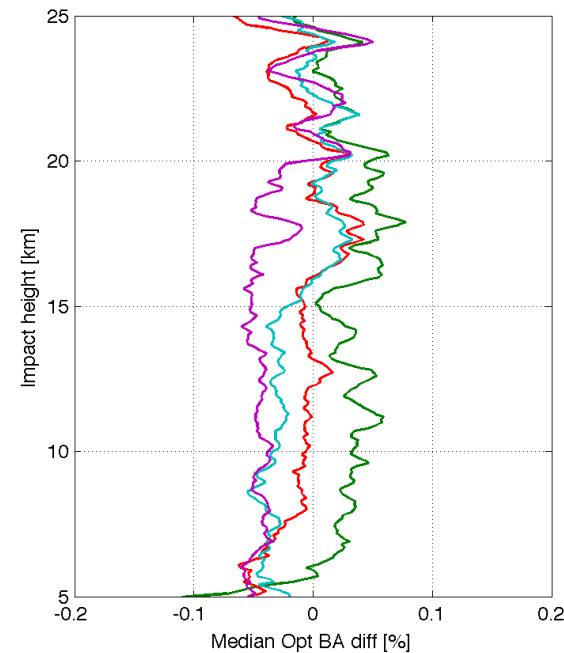
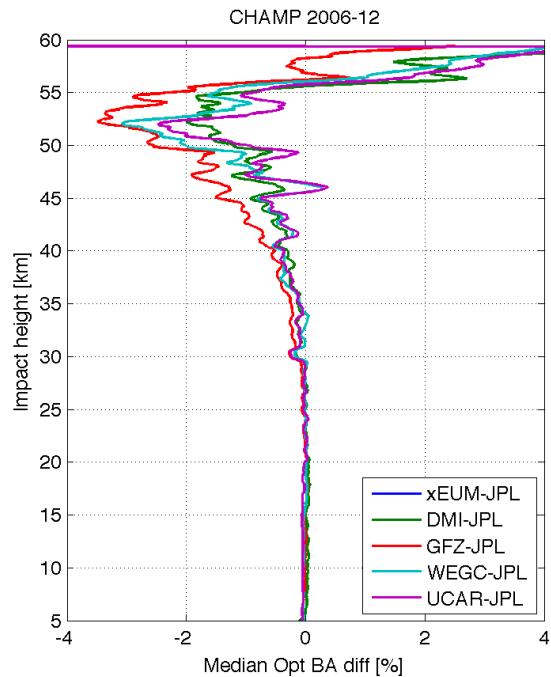
## Neutral BA



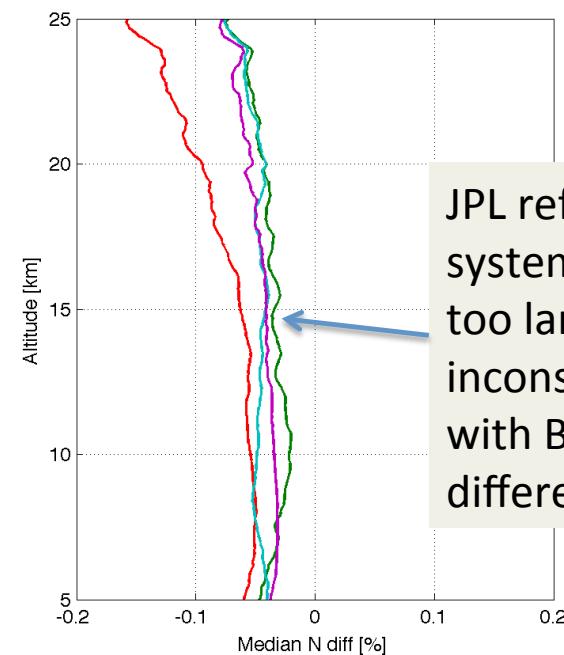
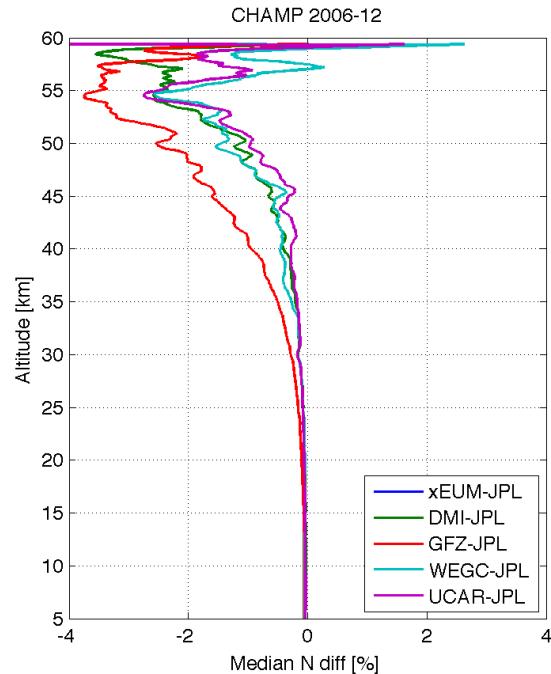
## Optimized Neutral BA



# Optimized Neutral BA



# Refractivity

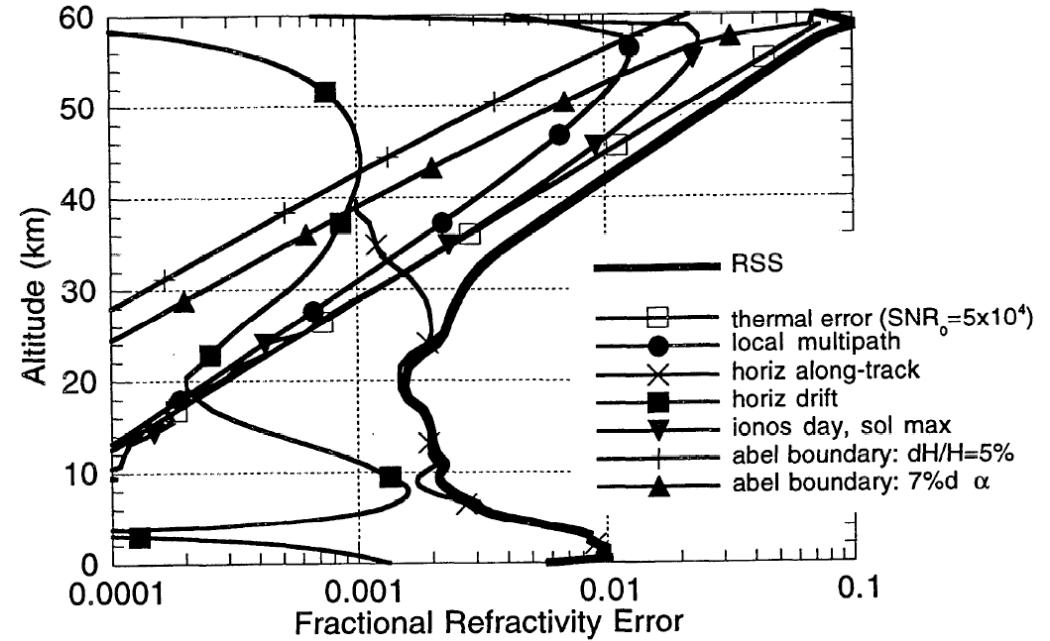


# Summary

- **Inter-center comparison is extremely valuable in identifying small systematic biases in the retrieval system.**
- Quadratic phase smoothing caused a positive bias in JPL retrieval that increases with smoothing interval. This is fixed by using cubic smoothing.
- Remaining differences are not fully understood (details of iono correction?).
- Another puzzle relates to inconsistent refractivity vs BA differences in the UTLS.
  - Geoid/height differences account for < 0.01%
  - Implementation of Abel inversion?

# Residual Ionospheric Error (RIE)

- The ionospheric correction currently employed by all centers only removes the leading order of ionospheric effect ( $\sim 1/f^2$ ).
- RIE is a potentially dominant source of systematic error. Moreover, it has a strong diurnal and solar cycle dependence.



Kursinski et al., *JGR*, 1997

0.1% at 30 km during  
solar-max daytime

# A Promising Approach

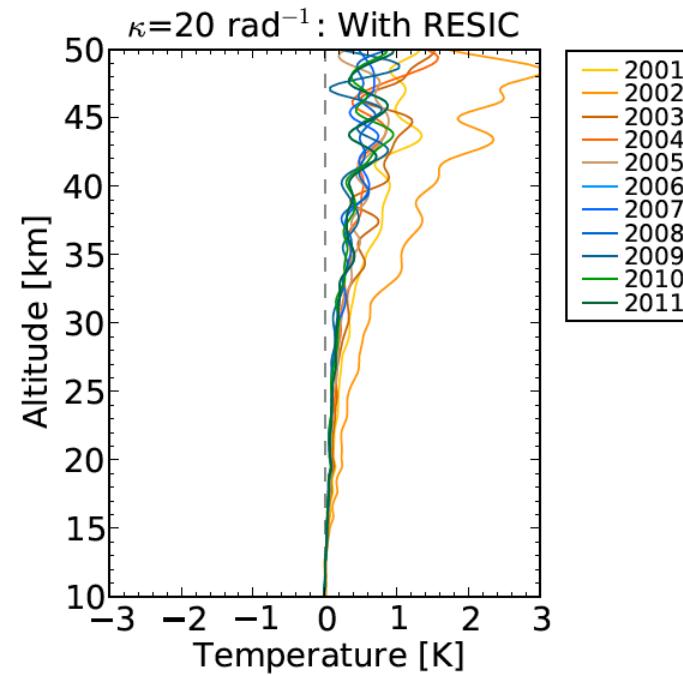
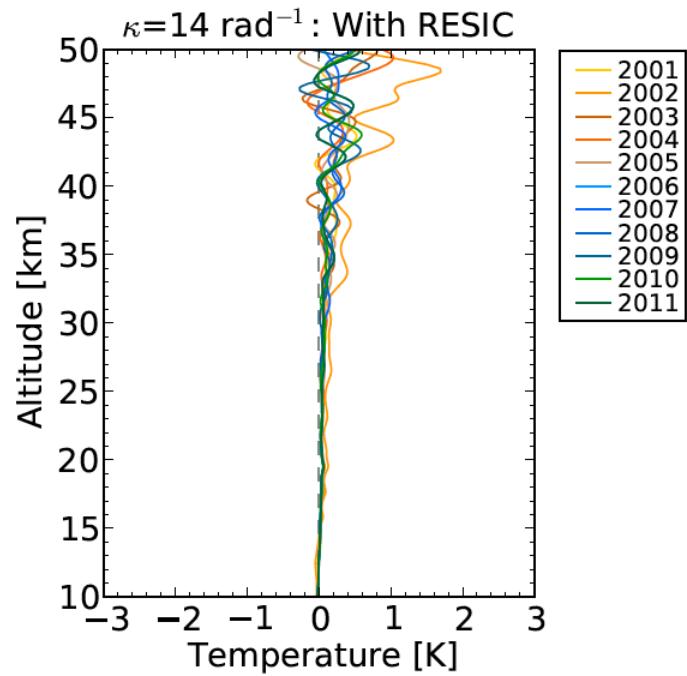
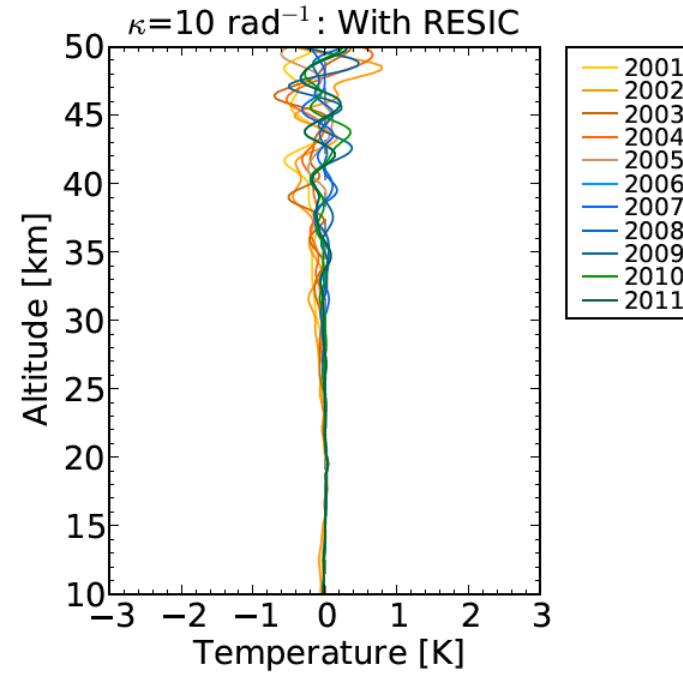
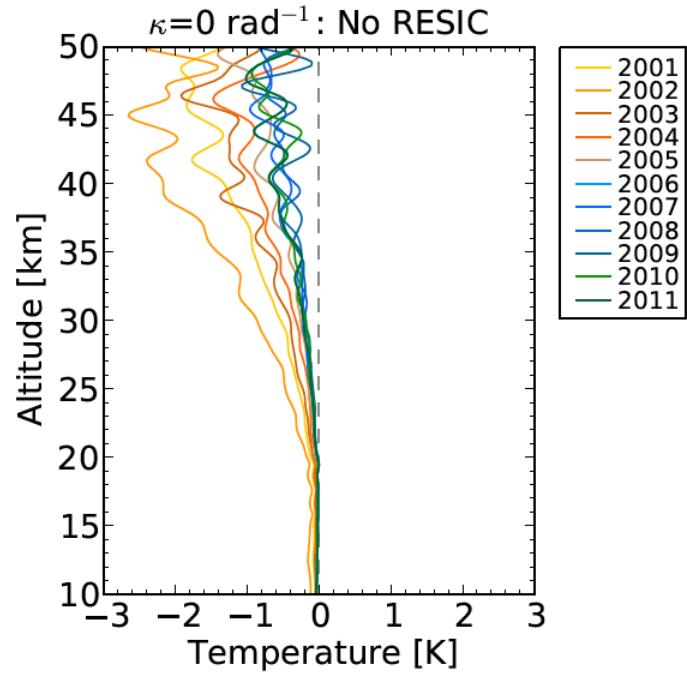
- Recently a new method has been proposed by Danzer et al. [AMTD, 2015] to remove RIE.

$$\Delta\alpha(a) = \alpha_C(a) - \alpha_N(a) = -\kappa(a)(\alpha_1(a) - \alpha_2(a))^2 ,$$



Slowly varying with height and does not vary significantly with solar activity

- They performed a simulation study to test this idea.



# Uncertainty in Refractivity Coefficients

- The refractivity formula relates microwave propagation bulk properties to atmospheric variables:

$$N = k_1 \frac{p_d}{T} + k_2 \frac{p_w}{T} + k_3 \frac{p_w}{T^2}$$

- These coefficients ( $k_1$ ,  $k_2$ ,  $k_3$ ), often assumed constant, are based on old measurements with insufficient uncertainty characterization [Aparicio and Laroche, *JGR*, 2011, proposed alternative expression with estimated 0.01% uncertainty].
- In addition,  $k_1$  can change as atmospheric composition changes (CO<sub>2</sub> doubling can increase  $k_1$  by ~ 0.05%, although this effect might be canceled out by corresponding reduction in O<sub>2</sub> [Foelsche et al., IROWG-4]).
- **There is a strong need for better measurements. NASA and ESA have both expressed interests in supporting this activity.**

# Acknowledgments

- We thank the representatives from various RO processing centers for providing the data used in this study and helpful discussions.
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